

**AN INTRODUCTION TO
SPACE INFLATABLE/RIGIDIZABLE
STRUCTURES TECHNOLOGY AT JPL**

Michael C. Lou

**Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA.**



SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



WHAT ARE SPACE INFLATABLE STRUCTURES?

- Large space structures that are deployed by pressurization. (Others are mechanically deployed or erected/assembled in space)
- A space inflatable structure, in general, is made of one or more long tubular elements (called booms or tubes).
- These tubular elements are highly flexible when not being pressurized - such that they can be stowed in a very small volume for launch.
- The stowed tubular elements are deployed in space by gas pressurization to achieve their designed configurations.
- Applications of space inflatable structures include radar antennas, sunshades, solar arrays, telescope reflectors, solar sails, and solar concentrators.



SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



WHY USE SPACE INFLATABLE STRUCTURES?

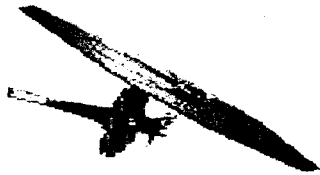
- Launch cost is a major part of the life cycle cost of a space flight mission.
- Payload mass and volume are important drivers of launch cost.
- Space inflatable (inflation deployable) structures technology offers order-of-magnitude mass and volume reductions for future space flight systems.
- Additional advantages of a space inflatable structure over its mechanically deployed counterpart include:
 - Design simplicity (10's of parts vs. 100's of parts)
 - Lower development cost
 - Higher deployment reliability



SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



TWO EXAMPLE APPLICATIONS OF SPACE INFLATABLE STRUCTURES



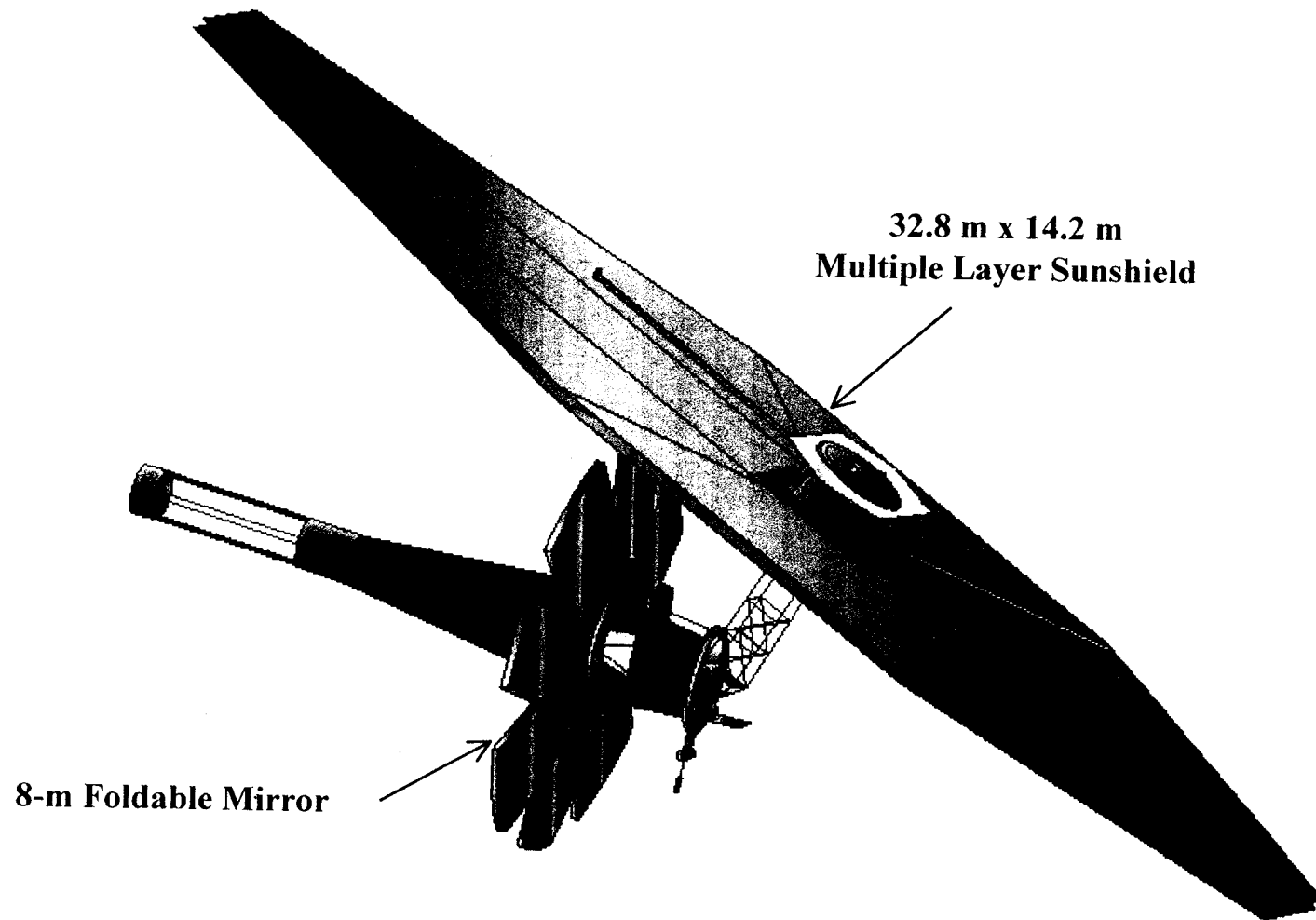
- (1) Inflatable Sunshield for the Next Generation Space Telescope (NGST)



- (2) Inflatable Synthetic-Aperture Radar (SAR) Array Antenna



NGST REFERENCE ARCHITECTURE





SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



NGST INFLATABLE SUNSHIELD

- Next Generation Space Telescope (NGST) is scheduled to be launched in 2007 as a replacement of Hubble Space Telescope (HST).
- NGST requires a 32.8 m x 14.2 m sunshield to passively cool the near IR telescope to an operating temperature of < 60 K.
- Requirements of NGST sunshield include:
 - Ultra lightweight
 - High packaging efficiency
 - High deployment reliability
 - 5 -10 years of mission life at L2
- A sunshield consisting of inflatable structures and multiple layers of thin thermal films is considered.



SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



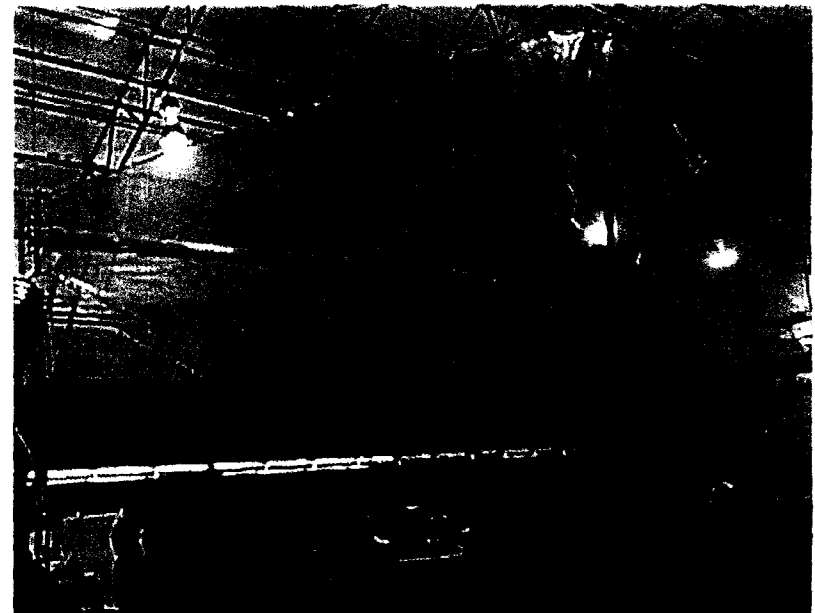
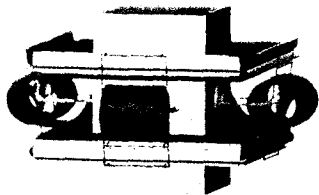
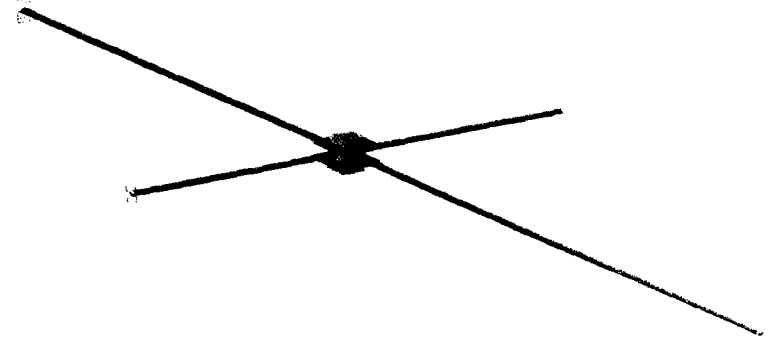
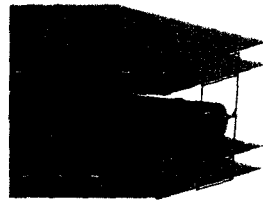
NGST INFLATABLE SUNSHIELD (Cont'd)

- An inflatable NGST sunshield has many advantages over its mechanically deployed counterpart:
 - 20 - 30% lighter
 - 60 - 80% smaller launch volume
 - Less complicated - 10's of parts vs. 100's
 - Cheaper - \$5-M vs. \$10+M
- A major concern is controllability of inflation deployment.
- A 1/2-scale engineering model was developed to test-verify controlled deployment and rigidization.
- NASA is currently preparing for an inflatable sunshield space experiment (Inflatable Sunshield In Space or ISIS) - Scheduled to be launched in the Space Shuttle in 2001.



NGST INFLATABLE SUNSHIELD ENGINEERING MODEL

JPL
Jet Propulsion Laboratory
California Institute of Technology





SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



ARTP INFLATABLE SAR

- Synthetic-Aperture Radar (SAR) missions are needed to monitor environmental conditions and resources of planet Earth - Antenna is too big and too heavy.
- JPL was tasked by NASA to develop an advanced ultra-lightweight SAR array antenna with specific RF requirements:
 - 10 m x 3 m aperture
 - L-Band (1.25 GHz operating frequency)
 - 80 MHz bandwidth
 - Dual polarization
- Radar array is formed by three parallel RF membrane layers:
 - Top layer is the radiating plane
 - Middle layer is the ground plane
 - Bottom layer is the micro-strip transmission line plane.

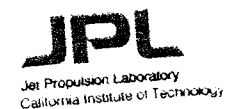


SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY

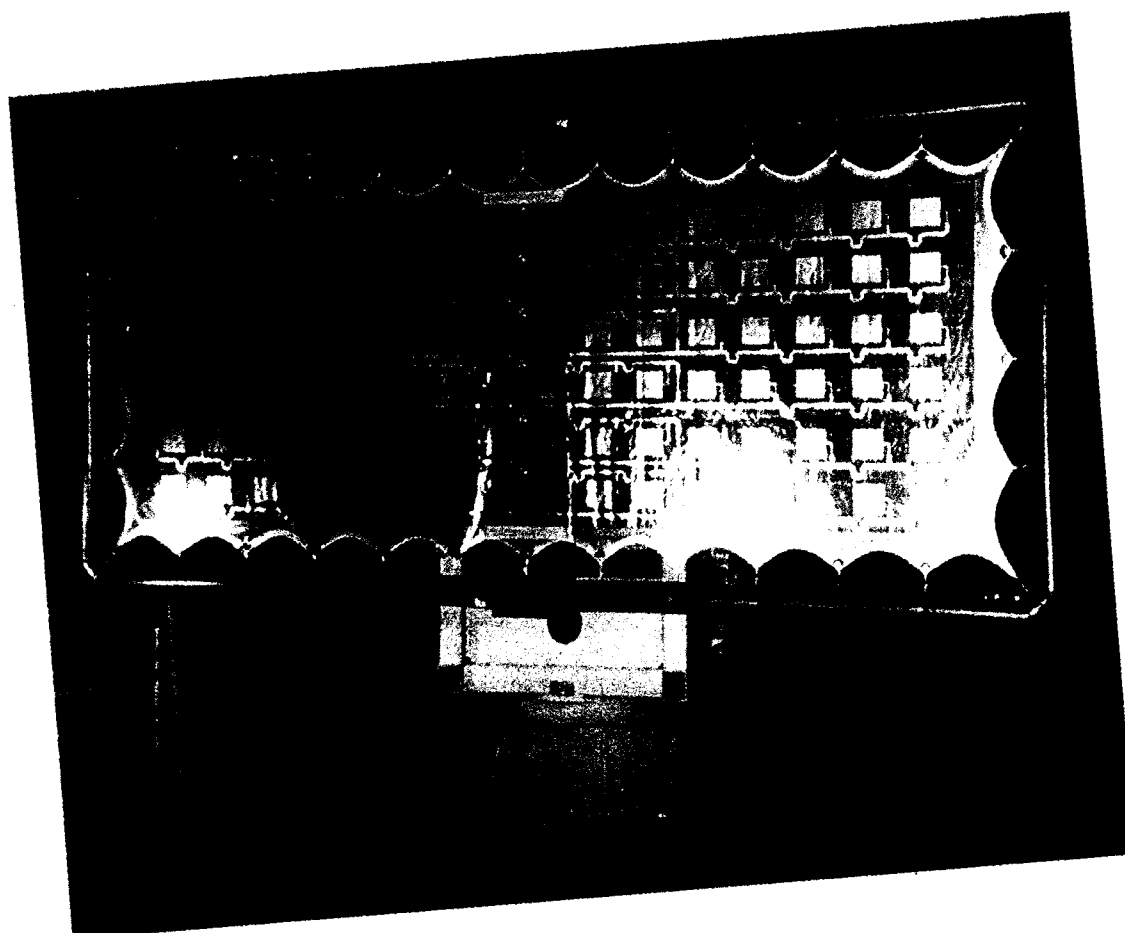


ARTP INFLATABLE SAR (Cont'd)

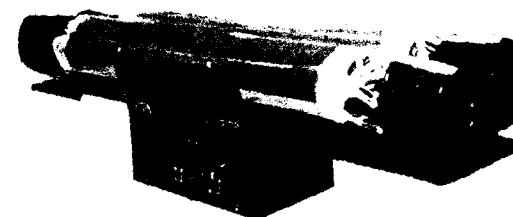
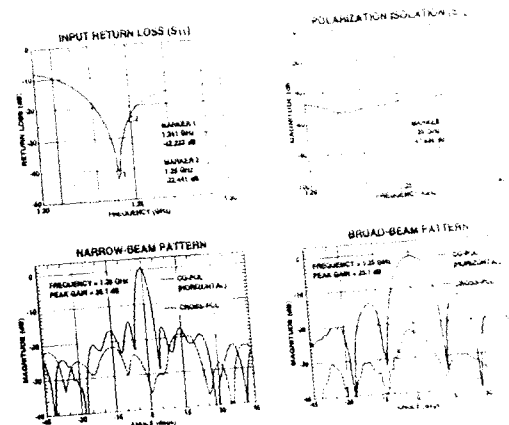
- Mechanical Requirements:
 - Lightweight (less than 3 kg/m² of system mass)
 - Small launch volume (targeted for small L/V such as Taurus or Athena)
 - Planarity and uniform separations for the three RF membrane layers
 - ♦ Flatness to be +/- 1 cm
 - ♦ Separation between the top and the middle layers to be 1.26 +/- 0.7 cm
 - ♦ Separation between the middle and the bottom layers to be 0.63 +/- 0.5 cm
- RF-functional 1/3-scale engineering models have been built by ILC Dover and L'Garde. The L'Garde model features an inflatable frame with stretched aluminum laminate booms.
- As a precursor to the inflatable SAR flight experiment (ISAR), a full-scale, single-wing engineering model is being developed at JPL for deployment and vibration tests.



ARTP INFLATABLE SAR



INFLATABLE SAR ARRAY ANTENNA RF TEST RESULTS





SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



TECHNICAL CHALLENGES

- Space applications of inflatable structures were studied in the 1960s. (e.g., NASA's ECHO missions)
- In May 1996, the Inflatable Antenna Experiment (IAE) mission was flown on a Spartan free flyer launched by the Space Shuttle.
- The IAE has generated much interest in space inflatable structures and systems. Post-flight reviews indicated that many technical challenges remain to be addressed. The major ones are:
 - Deployment Control
 - Space Rigidization
 - Modeling and Analysis Tools
 - Materials Characterization and Long-Term Space Survivability



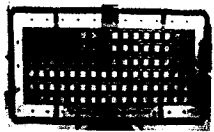
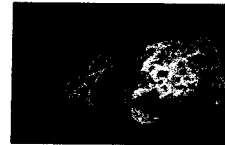
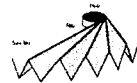
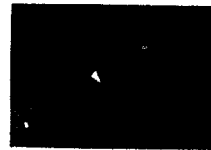
SPACE INFLATABLE/RIGIDIZABLE STRUCTURES TECHNOLOGY



Long-Range Technology Development Roadmaps



Large Lightweight Space Structures Low-Precision Applications



Inflatable Structures

- Simple inflatable structures
- Off-the-shelf materials
- Specialized design and analysis tools
- Scaling laws and ground test methods
- Experimental rigidization

Enables simple structures of up to about 50 m

- Space Demo and Tech Validation
- ST-5, ISIS, ISAE

Space Rigidization & Survivability

- Long-term (> 3 years) space survivability
- Space-durable materials and thin-films
- Space-validated rigidization
- Space-validated analysis and performance simulation capabilities
- 10 g/m² solar sails

Enables 100-m planar structural systems and 200-m solar sails

- GeoStorm Warning
- NGST Sunshade
- Lightweight, Low-Cost SAR Missions
- S/A and S/S for ESS Missions

Structures for Extreme Space Environments

- Survivability in extreme space environments
- Adaptive structures
- $\leq 1\mu$ -thick thin films
- ≤ 5 g/m² solar sails

Enables smart structural systems and 800-m solar sails

- Outer Planet Missions
- Interstellar Missions

Space Adaptation & Fabrication

- In-orbit configuration change and expansion
- Self-monitoring and self-reparable
- Space-based fabrication & assembly

Enables adaptive and expandable space structural systems

- Interstellar Missions
- Evolving Space Colonies

2001

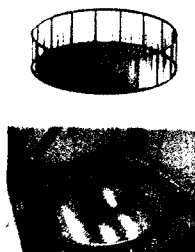
2007

2015

2025



Large Lightweight Space Structures Hi-Precision Apertures



D/ϵ of up to 10^4

- Inflatable torus and thin-film lenticular
- Deployable FRP truss and wire mesh dish
- Improved fabrication and assembly
- Hi-efficiency packaging concepts

Enables reflectors & concentrators with $D \leq 20$ m and $\epsilon = \text{mm's}$

- RF Reflectors
- Technology Validation in Space



D/ϵ of up to 10^5

- Long-term space survivability
- Space rigidizable structures
- Thin-film lenticular or hybrid reflective surface
- μm -level fabrication, assembly and ground measurements
- Space-validated analysis capabilities

Enables reflectors & concentrators with $D \leq 40$ m and sub-mm ϵ

- ARISE
- Space Solar Power
- Solar Propulsion



D/ϵ of up to 10^8

- Actively controlled structures
- Adaptive thin-film optics
- In-space aperture precision adjustment
- Sub- μm fabrication, assembly and ground testing
- Flat membrane mirrors

Enables large apertures with $D \leq 100$ m and $\epsilon = \mu\text{m's}$

- TPF
- Optical Communication
- Earth Science Event Monitors
- Exo-Planet Spectroscopy
- Exo-Planet Imaging



D/ϵ ratio of up to 10^{10}

- Break-through system concepts
- Breakthrough materials, fabrication, and test methodologies
- Multi-stage active wavefront correction

Enables large apertures with $D \leq 1000$ m and sub- μm ϵ

- Deep-Field Imaging Observatories

D : Aperture Diameter
 ϵ : RMS Surface Error

2001

2007

2012

2025